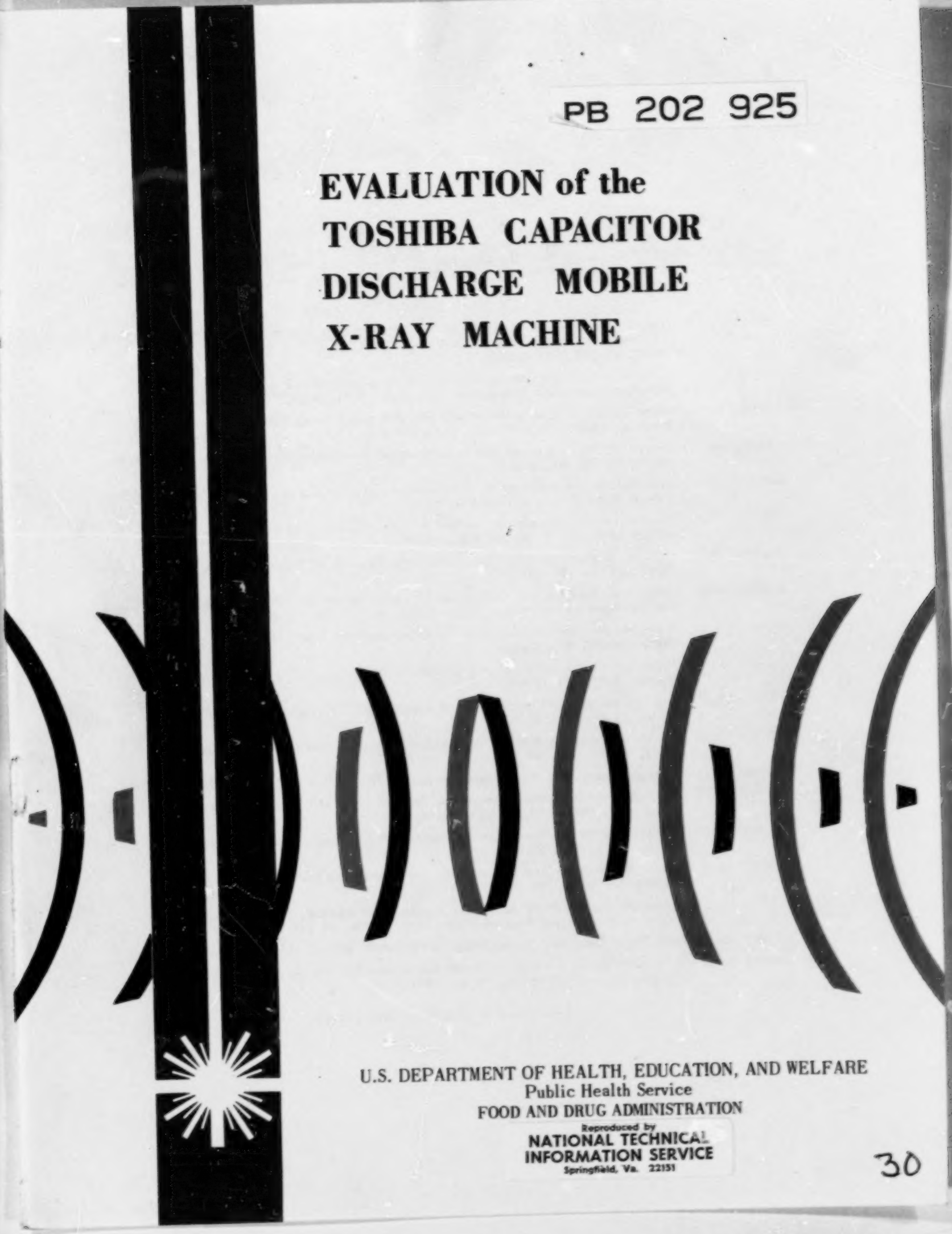
PB 202 925

EVALUATION of the TOSHIBA CAPACITOR DISCHARGE MOBILE X-RAY MACHINE



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EVALUATION of the TOSHIBA CAPACITOR DISCHARGE MOBILE X-RAY MACHINE

Details of illustrations in this document may be better studied on microfiche

G.F. Grove, Jr.

X-ray Exposure Control Labaratory
Division of Electronic Products

August 1971

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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Within the Bureau, the Division of Electronic Products (1) develops and administers performance standards for radiation emissions from electronic products, (2) studies and evaluates emissions of and conditions of exposure to electronic product radiation and intense magnetic fields, (3) conducts or supports research, training, development, and inspections to control and minimize such hazards, and (4) tests and evaluates the effectiveness of procedures and techniques for minimizing such exposures.

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John C. Villforth

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Director
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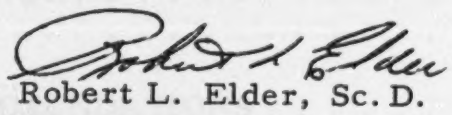
PREFACE

The Radiation Control for Health and Safety Act of 1968 authorizes the Secretary of Health, Education, and Welfare to establish an electronic product radiation control program which includes the development and administration of performance standards to control the emission of electronic product radiation. Performance standards are currently being developed for diagnostic x-ray equipment used by practitioners of the healing arts. To develop appropriate standards for new x-ray apparatus such as capacitor discharge equipment, typical operational data must first be obtained.

This report reflects the efforts of the Division of Electronic Products to keep informed of new and unusual types of commercial x-ray equipment and to gather information related to operating characteristics and radiation exposure in the use of such equipment. It presents the results of measurements made to determine the physical and operating characteristics of the Toshiba KCD-10M-6 capacitor discharge mobile x-ray machine. Although the results presented herein are considered accurate, they are not intended to certify that the Toshiba machine complies with forthcoming performance standards, nor should the test methods used in this study be considered the official methods for determining compliance.



Robert L. Elder, Sc. D.
Director
Division of Electronic Products

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ABSTRACT

Tests were performed on a Toshiba KCD-10M-6 capacitor discharge mobile x-ray machine to determine accuracy of voltage indications, the relationship between voltage setting and current-time values, line voltage effects and current drain, exposure reproducibility, focal spot size and location, correspondence between the collimator and light localizer, inherent filtration, half-value layer, radiation output, and tube housing and collimator leakage. Spurious radiation was found to originate in the tube under certain conditions. These conditions were investigated, and the observed radiation levels are reported.

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EVALUATION OF THE TOSHIBA CAPACITOR DISCHARGE MOBILE X-RAY MACHINE

1. INTRODUCTION

Although the capacitor discharge principle of x-ray generation is not new, it has not been in general use in the United States until recently. Five manufacturers are currently producing mobile capacitor discharge x-ray machines for sale in the United States, and the use of these machines is spreading. This is the third in a series of Division of Electronic Products reports on the various makes available.

The capacitor discharge principle is employed in a mobile radiographic unit so that the machine can be operated from a normal low-current wall outlet, eliminating the need for special wiring at the various locations where use is intended. Such operation is possible because a charge sufficient to produce a reasonable x-ray exposure in a short time is stored in capacitors prior to exposure. The charge is accumulated over a much longer time period, eliminating the sudden surge during exposure required by conventional equipment.

Although the results reported herein are considered accurate, the test methods used in this study should not be considered as the official methods for determining legal compliance with forthcoming performance standards for diagnostic x-ray equipment which are to be issued at a later date under the authority of the Radiation Control for Health and Safety Act of 1968.

2. DESCRIPTION OF TOSHIBA MACHINE

The unit tested, a Toshiba model KCD-10M-6 mobile capacitor discharge x-ray machine, serial number 70702405, was obtained from Profexray, the U.S. distributor, for the purpose of this evaluation. A photograph of the machine is shown in figure 1, and the manufacturer's specifications are listed in appendix A. The wheels are fitted with brakes which are released whenever the brake release bar is held in toward the main handle. The unit can be moved by one person. The tube head can be oriented in any direction normally required, and the collimator can be rotated about the axis of the beam. Friction locks are available for all motions. The face plate of the collimator is 25 cm from the focal spot, but guard rails extend to 30 cm to indicate the minimum recommended source-skin distance. A source-skin distance of 25 cm can be realized with extremeties by placing them between the rails which are 17 cm apart. The cassette box is located inside the cabinet and is lined with lead only on the side that is adjacent to the outside of the machine and farthest from the x-ray tube.

The control panel and hand switch are shown in figure 2. The LV control compensates for different line voltages, and the meter indicates the correct setting. The kV control determines the initial voltage to be placed on the capacitors, with half the total voltage on the anode and half on the cathode. The meter measures the anode or cathode voltage, which can be selected by an internal switch, and the meter scale indicates twice the voltage on the side measured. The toggle switch on the control panel offers two mAs choices for a given kV setting. The hand switch has three buttons and a light. When the "charge" button is pressed, charging of the capacitors is initiated, and the light indicates that they have been charged to the selected value. Pressing the "ready" button causes the filament to heat and the anode to rotate. Pressing the "x-ray" button initiates the exposure.

A block diagram of the circuit is shown in figure 3. Solid lines indicate specific circuit connections, while dotted lines indicate information flow. When the charge button is pressed, the control circuits energize the high-voltage supply which charges the capacitors. The anode and the cathode each have capacitors to ground which are charged respectively to plus and minus one-half the total voltage.

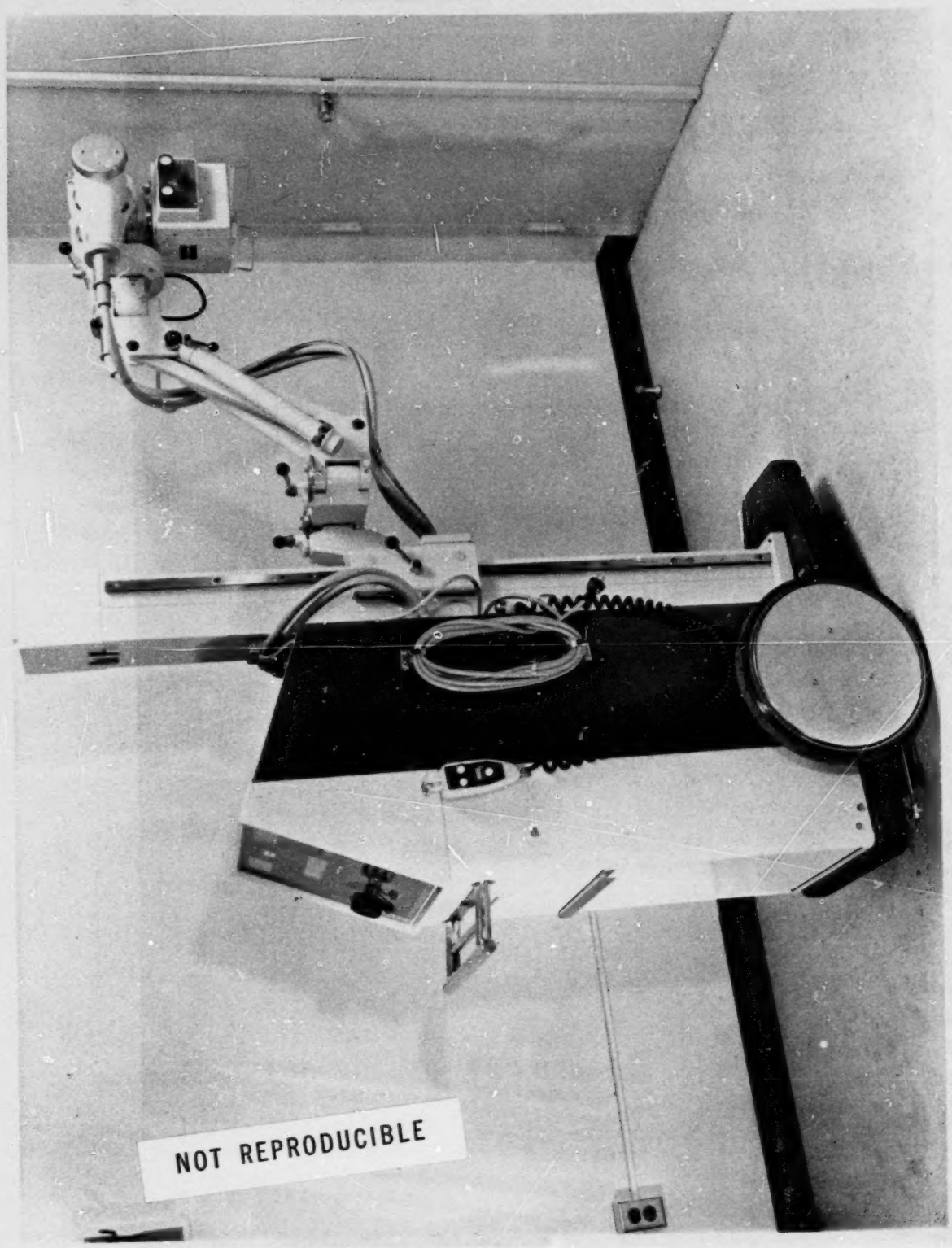

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Figure 1. Toshiba capacitor discharge mobile x-ray machine.

Figure 2. Control panel and hand switch of Toshiba machine.

When the preset voltage is reached, the kV-sensing circuit causes the high-voltage supply to be deenergized. The capacitor voltage appears across the tube at all times, but the tube is grid-controlled and normal tube conduction is suppressed by application of a negative bias on the grid.

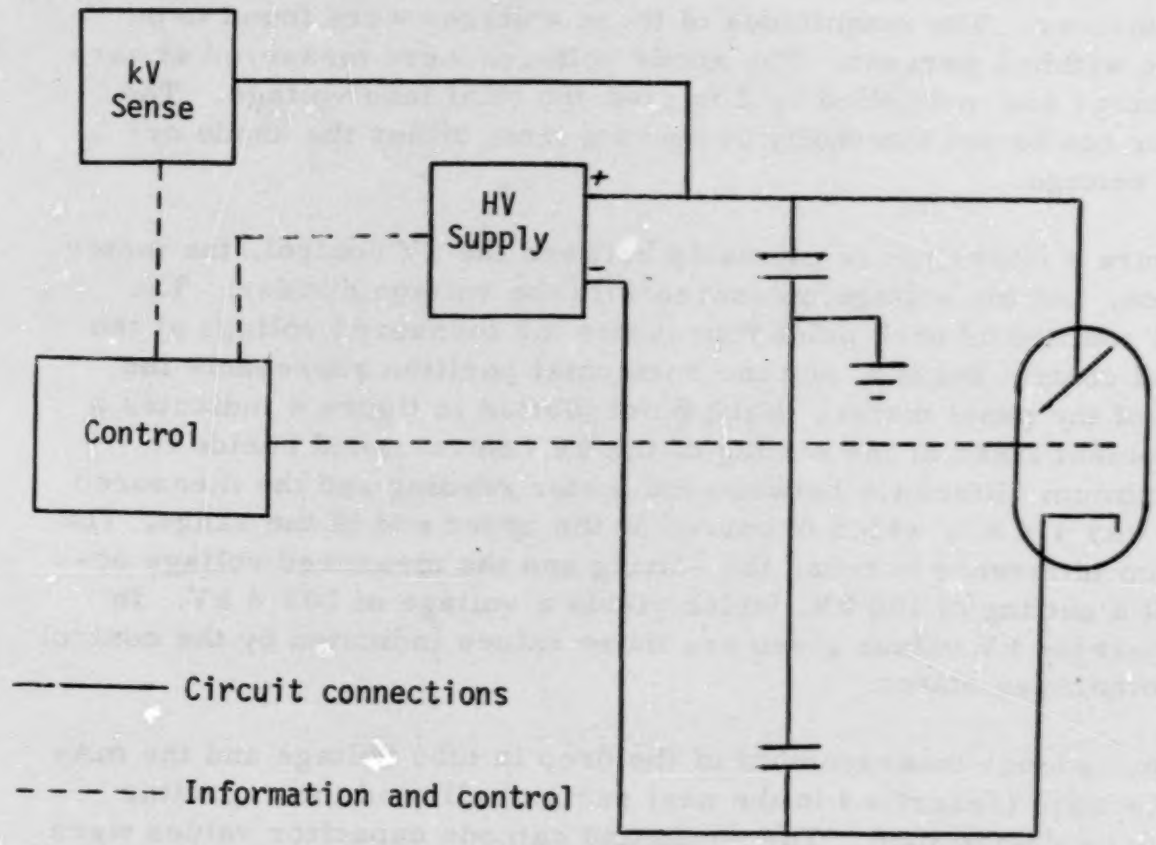

Figure 3. Block diagram of Toshiba machine circuit.

When an exposure is to be made, pressing the ready button causes heating of the tube filament and initiates anode rotation The ready button operates a relay which maintains the machine in the ready state, even if the button is released, until an exposure is made or the charge button is pressed. After 1 second in the ready mode, if the x-ray button is pressed, the grid bias is removed and current through the tube causes production of x rays. The kV-sensing circuit stops the exposure by reapplying the grid bias after the capacitors have discharged to a voltage predetermined by the kV setting and the "short time"/"high density" selector switch The capacitors, which have a nominal combined value of 1.0 μF, discharge about 1 kV for each mAs of exposure.

3. MEASUREMENTS AND TESTS

3.1 VOLTAGE MEASUREMENTS

The anode and cathode voltages were measured with a resistance voltage divider. The magnitudes of these voltages were found to be the same within 1 percent. The anode voltages were measured at various settings and multiplied by 2 to give the total tube voltage. The kV meter can be set internally to operate from either the anode or cathode voltage.

Figure 4 shows the relationship between the kV control, the meter indication, and the voltage measured with the voltage divider. The vertical position of each point represents the measured voltage at the indicated control setting, and the horizontal position represents the reading of the panel meter. Each point plotted in figure 4 indicates a measurement taken at the setting of the kV control noted beside it. The maximum difference between the meter reading and the measured voltage was 4.4 kV, which occurred at the upper end of the range. The maximum difference between the setting and the measured voltage occured at a setting of 100 kV, which yields a voltage of 103.4 kV. In this report the kV values given are those values indicated by the control unless otherwise stated.

Simultaneous measurement of the drop in tube voltage and the mAs of an exposure (described in the next section) allowed the capacitor values to be determined. The anode and cathode capacitor values were found to be 2.2 F and 2.3 μF respectively, resulting in a series value of 1.1 μF. Each capacitor is shunted with a 400-megohm bleeder resistor which causes its voltage to decay exponentially with a time constant of about 13 minutes.

A 20-second time delay is built in and allows a warmup period before the machine can be operated. By the end of this period, the charging voltage stabilizes to within 1 kV of its final value. The times required for charging were 5 seconds to 70 kV and 15 seconds to 100 kV. No method is provided for discharging the capacitors completely without removing the cables.

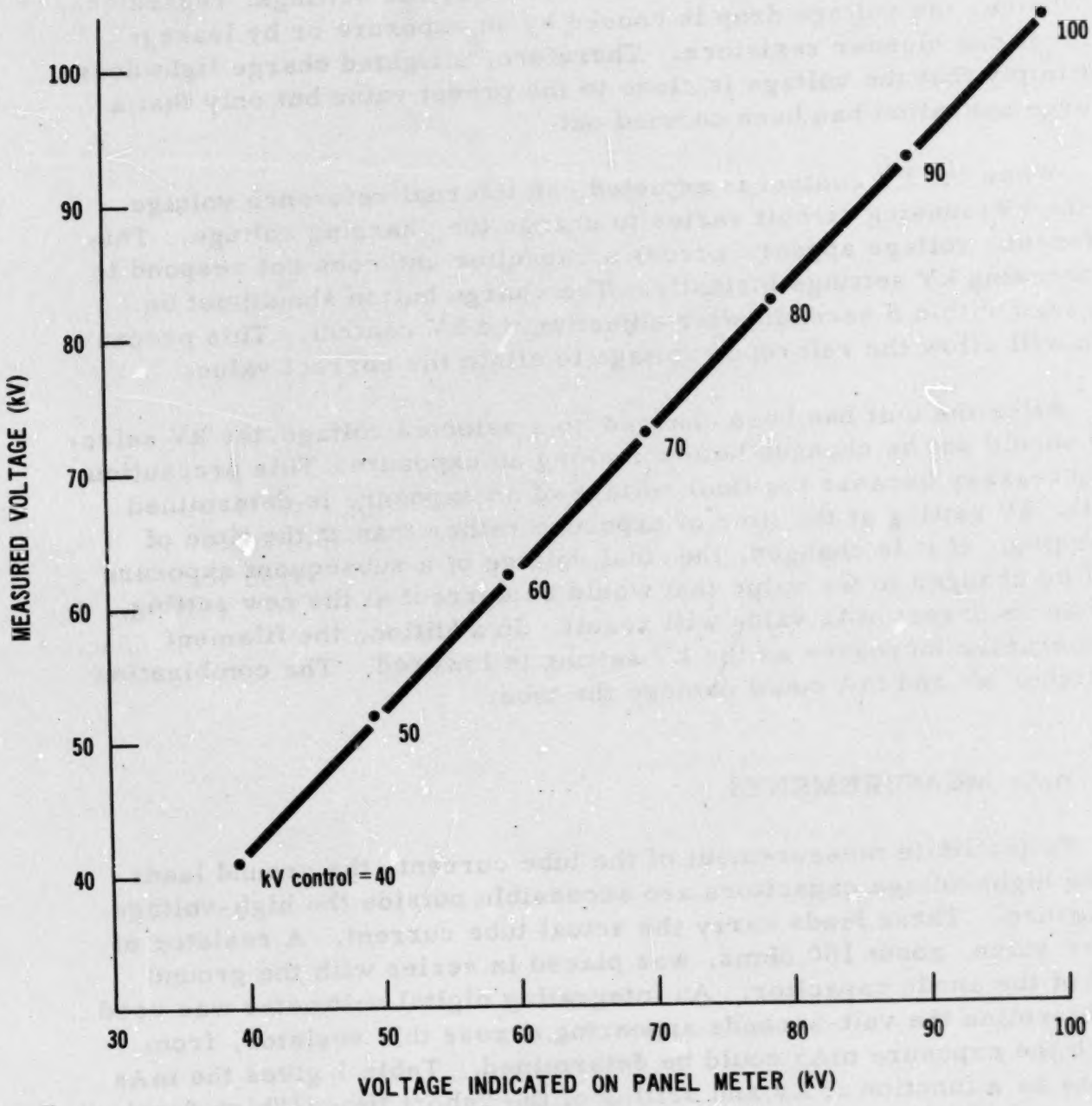

Figure 4. Measured versus indicated kV for Toshiba machine at noted kV control settings.

The charge light on the remote switch lights up when charging stops at the preset voltage. It remains on until the voltage falls to the cutoff voltage of the exposure indicated by the settings, regardless of whether the voltage drop is caused by an exposure or by leakage through the bleeder resistors. Therefore, a lighted charge light does not imply that the voltage is close to the preset value but only that a charge operation has been carried out.

When the kV control is adjusted, an internal reference voltage in the kV-sensing circuit varies to change the charging voltage. This reference voltage appears across a capacitor and does not respond to decreasing kV settings instantly. The charge button should not be pressed within 5 seconds after adjusting the kV control. This precaution will allow the reference voltage to attain the correct value.

After the unit has been charged to a selected voltage, the kV selector should not be changed before making an exposure. This precaution is necessary because the final voltage of an exposure is determined by the kV setting at the time of exposure rather than at the time of charging. If it is changed, the final voltage of a subsequent exposure will be changed to the value that would be correct at the new setting, and an incorrect mAs value will result. In addition, the filament temperature increases as the kV setting is lowered. The combination of higher kV and mA could damage the tube.

3.2 mAs MEASUREMENTS

To facilitate measurement of the tube current, the ground leads of the high-voltage capacitors are accessible outside the high-voltage enclosure. These leads carry the actual tube current. A resistor of known value, about 100 ohms, was placed in series with the ground lead of the anode capacitor. An integrating digital voltmeter was used to determine the volt-seconds appearing across this resistor, from which the exposure mAs could be determined. Table 1 gives the mAs values as a function of kV and setting of the "short time"/"high density" selector switch.

Table 1. Measured mAs for various exposures.

kV setting	mAs per exposure	
	"Short time" setting	"High density" setting
40	17.1	26.3
55	21.5	35.7
70	24.6	43.8
85	25.7	51.0
100	26.1	58.5

An exposure can be made without the use of the ready button by pressing and holding the x-ray button. The filament is heated and anode rotation is started as soon as it is pressed, and an exposure will occur after a 1-second delay if the button is held down. About one in twenty exposures made this way will be interrupted one or more times rather than being continuous. The mAs value is not affected by these breaks, but the total time over which the exposure occurs is increased by as much as one-half.

3.3 LINE VOLTAGE AND CURRENT

To compensate for differences in line voltage, a line voltage control and meter are provided. The meter scale has a diamond marking to indicate the correct voltage. The width of the diamond indicates a variation of about ± 3 percent from the correct voltage. The range of control allowed correct adjustment for any line voltage between 85 and 140 volts. The operation of the machine was tested at the upper and lower edges of the diamond mark. The kV and mAs are proportional to line voltage and vary ± 3 percent as the line voltage changes from one edge of the mark to the other. The instantaneous current changes rapidly in this range, which may cause overload or excessive exposure time if the line voltage is too far from the correct value. The line voltage should always be set and maintained at the proper level, and the width of the diamond mark should be considered to be the maximum permissible variation.

The peak current drawn from the line when the capacitors are charging is 30 amperes at 124 volts. After 5 seconds it is down to 12 amperes, and after 10 seconds it is 6 amperes. Standby current is less than 1 ampere.

3.4 EXPOSURE REPRODUCIBILITY

Exposure reproducibility was checked for "short time" exposure settings at 40, 60, 80, and 100 kV. Standard deviations were calculated from a sample of 20 exposures for each of the above voltages. The standard deviation of exposure varied between 2.1 and 2.7 percent.

3.5 FOCAL SPOT SIZE AND LOCATION

The location of the focal spot was determined by inserting a lead diaphragm with two pinholes 1.4 cm apart into the beam. The distance between the two focal spot images on film was used to calculate the distance from the focal spot to the pinholes. The average of several determinations showed that the focal spot was 24.7 cm behind the collimator face plate. The tape measure mounted on one end of the tube housing to indicate distance from the focal spot was accurate to within 0.4 cm.

The focal spot size was determined according to the method recommended by the ICRU.[1] An image of the focal spot was produced by placing a diaphragm with a 0.075-mm-diameter pinhole between the focal spot and the film. Several images were made at various distance ratios, and the effective focal spot size was found to be 2.7 by 2.5 mm.

3.6 BEAM COLLIMATION AND LIGHT LOCALIZER

The relationship between the x-ray beam and the light localizer was determined by marking the edge of the lighted area with lead pieces on a sheet of film. The film was then exposed with the lead markers in place. The edge of the light field is defined as the point where the intensity of the light, determined with a narrow-field light meter, is one-fourth of its level at the center. The edge of the x-ray beam is the point where the exposure, determined from the film density, is one-tenth of its level at the center.

An exposure was made at a source-film distance of 1 meter. The light field was 19.4 by 14.9 cm, and the x-ray field was 20.3 by 15.7 cm. The maximum error in a single edge was 0.7 cm.

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[1] INTERNATIONAL COMMISSION ON RADIOLOGICAL UNITS AND MEASUREMENTS. Report 10f 1962: Methods of evaluating radiological equipment and materials. National Bureau of Standards Handbook 89, page 1 (1963).

3.7 INHERENT FILTRATION

The inherent filtration of the tube housing was determined by comparison of attenuation curves with a machine of known filtration and voltage.[2] The machine used for comparison had 1 mm of beryllium in the x-ray tube and 1.5 mm beryllium and 0.25 mm aluminum added filtration, giving a total of about 0.3 mm aluminum equivalent filtration. The power-supply filtering of the comparison machine was such that the tube voltage peak was 98 kV and fell 4 kV between power-supply pulses. This variation between 94 and 98 kV is similar in effect to the variation in tube voltage in the Toshiba machine during a 98-kV 4-mAs exposure. The timing circuit was temporarily modified to allow such an exposure. Attenuation curves in aluminum were prepared at these operating conditions with identical geometry for the two machines. The kV and mAs values used were measured rather than indicated values. The curves extended to 5 mm aluminum for the Toshiba machine and to 10 mm for the comparison machine. Radiation measurements for the Toshiba curve were made with a Victoreen Integrating Ratemeter, model 555, and a 1DA chamber. Radiation from the comparison machine was measured with a free-air ionization chamber.

One attenuation curve was prepared for the Toshiba unit with only the tube housing window in the beam. This curve from 0 to 5 mm closely matched the comparison curve from 0.6 to 5.6 mm, indicating that the Toshiba tube head had approximately 0.6 mm more inherent filtration than the 0.3 mm of the comparison machine and, hence, that the inherent filtration of the Toshiba machine is about 0.9 mm. A similar comparison of curves indicated that the Toshiba tube head and collimator together had an inherent filtration of approximately 2.1 mm. There was no other added filtration.

3.8 HALF-VALUE LAYER

Attenuation in aluminum was measured and the first and second half-value layers determined from the resulting attenuation curves. Radiation measurements were made with a Victoreen Integrating Ratemeter, model 555, and a model 1DA ion chamber. Because energy dependence affects all measurements similarly, its effect on the attenuation curves was neglected. The chamber axis was parallel to

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[2] QUIMBY, E. H., L. S. TAYLOR, AND O. GLASSER ET AL. Physical Foundations of Radiology (3rd edition). Paul B. Hoeber, Inc., N. Y. pages 258-260 (1961).

the x-ray beam, and the center of the chamber was placed 100 cm from the focal spot. The attenuators and a lead sheet with a 1-inch hole were placed halfway between the focal spot and the center of the chamber. The lead sheet, placed next to the chamber side of the attenuators, limited the beam size to an area slightly larger than that of the chamber. Half-value layer measurements were not corrected to zero beam size as suggested by Trout,[3] because the maximum error from this cause is reported to be about 2 percent at 100 kV for the geometry used.

The first and second half-value layers in millimeters of aluminum and the homogeneity coefficients are given in table 2. The homogeneity coefficient is the ratio of the first and second half-value layers and gives an index of the energy distributions of the beam.

Table 2. Half-value layers and homogeneity coefficients.

Technique	1st HVL (mm Al)	2nd HVL (mm Al)	Homogeneity coefficient
40 kV, "short time"	1.1	1.3	0.85
40 kV, "high density"	1.1	1.3	0.85
70 kV, "short time"	2.0	2.7	0.74
70 kV, "high density"	1.8	2.5	0.72
100 kV, "short time"	2.9	4.5	0.64
100 kV, "high density"	2.5	4.0	0.63

3.9 RADIATION OUTPUT

The radiation output for various exposures was determined by using the same arrangement employed for determining half-value layers. Figure 5 is a graph of radiation output versus starting voltage for "short time" and "high density" settings of the selector switch.

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[3] TROUT, E.D., ET AL. Determination of half-value layer. Amer. J. Roentgen. 84:4:729 (1960).

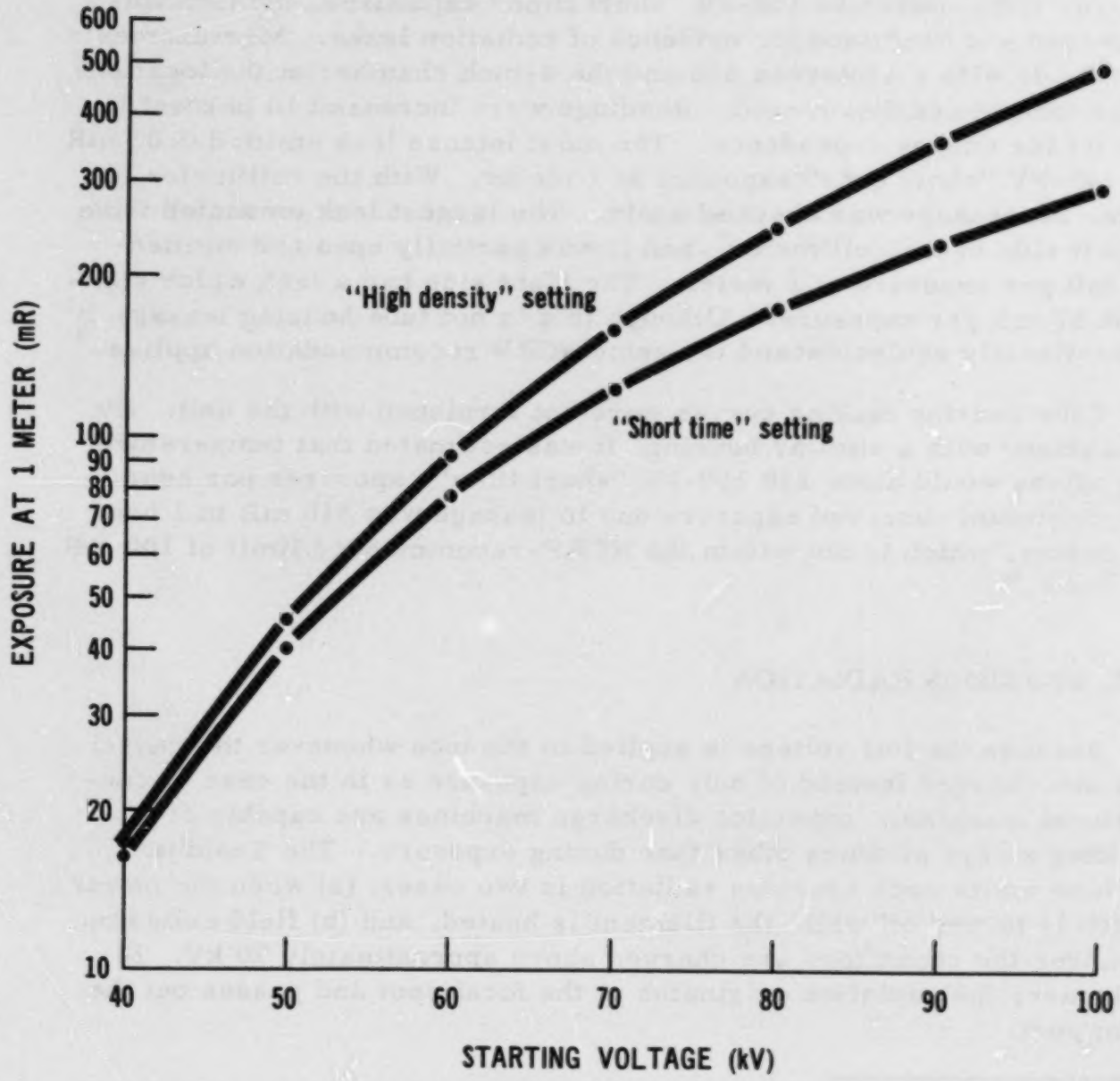

Figure 5. Output versus starting voltage of Toshiba machine at "high density" and "short time" settings of selector switch.

3.10 TUBE HOUSING LEAKAGE

With the beam port blocked with more than 10 half-value layers of lead, as recommended by the NCRP,[4] the tube housing was wrapped in x-ray film. After 10 100-kV "short time" exposures, the film was processed and examined for evidence of radiation leaks. Measurements were made with a Victoreen 666 and the 4-inch chamber at the locations where leaks were discovered. Readings were increased 10 percent to correct for energy dependence. The most intense leak emitted 0.03 mR per 100-kV "short time" exposure at 1 meter. With the collimator in place, the leakage was checked again. The largest leak emanated from the left side of the collimator when it was partially open and emitted 2.4 mR per exposure at 1 meter. The right side had a leak which emitted 0.57 mR per exposure. Although this is not tube housing leakage, it is functionally equivalent and the same NCRP recommendation applies.[5]

Tube housing cooling curves were not furnished with the unit. By comparison with a similar housing, it was estimated that temperature limitations would allow 210 100-kV "short time" exposures per hour. The maximum observed exposure due to leakage was 510 mR in 1 hour at 1 meter, which is not within the NCRP-recommended limit of 100 mR in 1 hour.[6]

3.11 SPURIOUS RADIATION

Because the full voltage is applied to the tube whenever the capacitors are charged instead of only during exposure as in the case of conventional machines, capacitor discharge machines are capable of emitting x rays at times other than during exposure. The Toshiba machine emits such spurious radiation in two cases: (a) when the power switch is turned off while the filament is heated, and (b) field emission whenever the capacitors are charged above approximately 70 kV. In each case, the radiation originates at the focal spot and passes out the beam port.

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[4] NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS. Report No. 33: Medical X-ray and Gamma Ray Protection for Energies up to 10 MeV. NCRP, Washington, D.C., page 15 (1968).

[5] Ibid., page 12.

[6] Ibid., page 15.

(a) Power Switch Operation

If the power is turned off after the ready button has been pressed, a short pulse of radiation is emitted. This occurs because the filament is heated by the ready button and the grid bias is removed when the power is turned off. Current can then flow through the tube for a fraction of a second while the filament cools. The exposure from this pulse is 33 mR at 1 meter and 100 kV, measured with the 1-1/4-inch chamber. No pulse is emitted if the ready button has not been pressed because the filament has not yet been heated. The power switch should not be turned off after the ready button has been pressed unless the x-ray button has been pressed to cause an exposure or the charge button has been pressed to release the self-holding feature of the ready button. The prevention of radiation from this cause is not mentioned in the instruction manual, although the exposure is large enough to expose film at radiographic distances and also poses a potential hazard to the operator.

(b) Field Emission (Dark Current) Radiation

Whenever the capacitors are charged to a sufficient voltage, a small current flows in the tube. This occurs because the electric field strength at the grid is sufficient to cause electrons to be pulled from its surface and strike the anode. This small current is not affected by either grid bias or filament temperature. At 100 kV this field emission current produces observed exposure rates of 15 to 50 mR per hour at 1 meter. The exposure rate is variable, depending on tube temperature and history of operation. As the tube voltage falls, the intensity falls and is less than 1 percent of maximum at 70 kV. The voltage normally falls from 100 to 70 kV in 4 minutes, and the integrated exposures observed were between 0.13 and 1.4 mR at 1 meter. This is sufficient radiation to cause fogging of film when used with screens at normal distances. Because of the extreme variability of exposure, it is not known whether these observed exposures represent absolute limits. In addition, other tubes of the same type may differ significantly.

In addition to these observed cases of spurious radiation, the failure of the x-ray tube grid bias will result in exposures with large and uncontrollable mAs values. This occurs because the tube conducts as soon as the filament is heated by pushing the ready button, and the current flow is not stopped after the correct mAs is reached. The resulting

exposure discharges the capacitors to a low voltage, overexposing the film and the patient. This condition cannot be detected until an exposure is attempted and the operator notices that the kV meter begins falling before the exposure switch is operated. Such a failure did not occur during these tests, but the grid bias appears between two conductors of the cathode high-voltage cable and a breakdown is possible.

After the testing described above was completed, the manufacturer supplied two more tube housing assemblies for testing. Both tubes were tested to determine the field emission levels. One tube emitted 0.37 to 1.7 mR per hour at 1 meter and 100 kV. The maximum observed integrated exposure from one cycle of charging to 100 kV, allowing normal discharge through leakage, was 0.016 mR at 1 meter. The field emission exposure rate for the second tube was 0.01 to 2.5 mR per hour at 1 meter and 100 kV. The maximum observed integrated exposure rate was 0.023 mR at 1 meter.

4. CONCLUSIONS AND RECOMMENDATIONS

As a result of this evaluation, the Division of Electronic Products has made certain suggestions for improving the radiation safety of the Toshiba machine to Profexray, the U.S. distributor. In response to these recommendations, Profexray has agreed to the following physical changes on units manufactured after July 1, 1971:

(1) One-half millimeter of aluminum filtration will be added to the beam port.

(2) Additional shielding will be incorporated into the collimator to reduce radiation outside the primary beam.

(3) The circuitry associated with the hand switch will be modified to eliminate the locking feature of the ready button and eliminate the possibility of broken exposures caused by pressing only the x-ray button.

In addition to these changes, units produced after September 1, 1971, will have a shutter which blocks the beam port except during exposure. This shutter, which is designed to eliminate field emission radiation, will be fitted with a spring-closing system so that it will close if power is lost. Figure 6 shows the tube housing with the shutter installed, and figure 7 is a closeup of the collimator mounting bracket with the shutter in the open position.

In addition to these physical changes, instructions furnished with the unit will include a description of grid bias failure and a statement that charging should not be initiated within 5 seconds after changing the kV control setting.

NOT REPRODUCIBLE

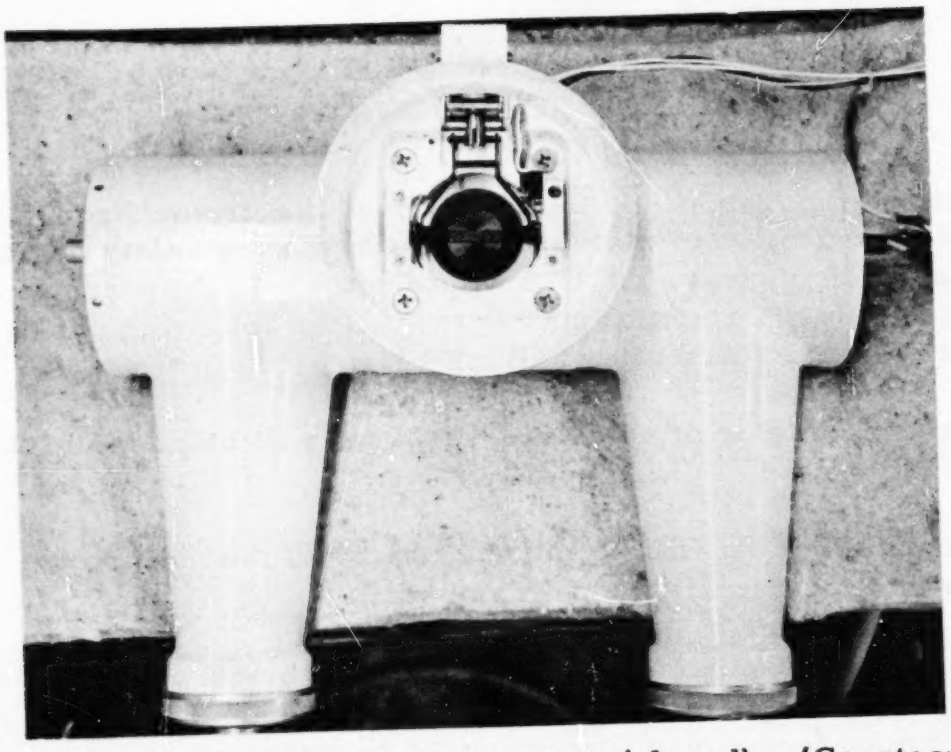

Figure 6. Prototype beam shutter (closed). (Courtesy Profexray Division, Litton Industries)

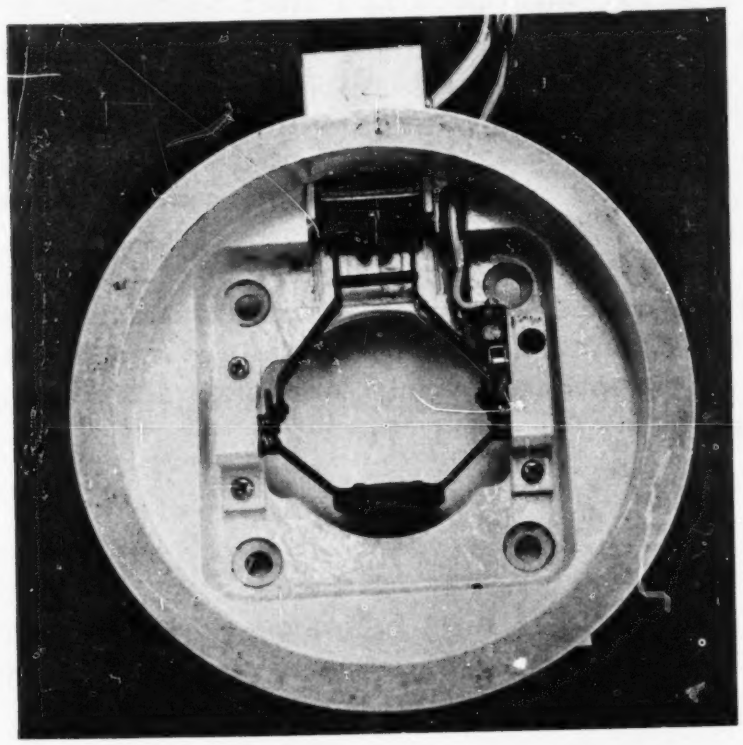

Figure 7. Prototype beam shutter (open) and mounting plate. (Courtesy Profexray Division, Litton Industries)

APPENDIX A

SPECIFICATIONS FOR TOSHIBA CAPACITOR DISCHARGE MOBILE X-RAY MACHINE

Manufacturer	Tokyo Shibaura Electric Co., Ltd.
U.S. Distributor	Profexray Division, Litton Industries
Overall length	1.1 meter
Overall width	0.7 meter
Overall height	1.8 meter
Maximum tube voltage	100 kV
Total capacitance	1.0 μF
Power requirement	80 - 140 volts single phase, 50 - 60 Hz, 1.5 kVA
X-ray tube	Grid controlled, rotating anode, 2.0 x 2.0 mm focal spot
Total filtration	2 mm aluminum equivalent
Net weight	310 kg

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G. F. Grove, Jr.
EVALUATION OF THE TOSHIBA CAPACITOR DISCHARGE MOBILE X-RAY MACHINE.

Accession No.

USDHEW, Public Health Service, Food and Drug Administration, Bureau of Radiological Health. DHEW Publication No. (FDA) 72-8006, BRH Publication No. BRH/DEP 72-1 (August 1971) 19 pp. (limited distribution).

ABSTRACT: Tests were performed on a Toshiba KCD-10M-6 capacitor discharge mobile x-ray machine to determine accuracy of voltage indications, the relationship between voltage setting and current-time values, line voltage effects and current drain, exposure reproducibility, focal spot size and location, correspondence between the collimator and light localizer, inherent filtration, half-value layer, radiation output, and

(over)

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KEYWORDS: Capacitor Discharge X-ray Machines; Mobile X-ray Machines; X-ray Equipment; X-ray Machine Evaluation.

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